Heartwood Formation in Loblolly and Longleaf Pines for Red-cockaded Woodpecker Nesting Cavities

Alexander Clark III, *USDA Forest Service, Southeastern Forest Experiment Station, Forestry Sciences Laboratory, Carlton Street, Athens, GA 30602*

Abstract: Information on the relationship of heartwood development to site quality, competitive index, tree age, and tree size for loblolly (*Pinus taeda* L.) and longleaf (*P. palustris* Mill) pine is presented. Twenty-nine loblolly and 26 longleaf pine stands representing a range of age classes (30 to 170 years) and site indices (12 to 37 m) were sampled in the Southeast. At age class 50, a portion of the loblolly pine growing on site index 24 m and better sites contained sufficient heartwood (≥ 12.7 cm at 6.7 m) for red-cockaded woodpecker (*Picoides borealis*) (RCW) cavity activity. None of the longleaf pine contained sufficient heartwood until age class 60 because the longleaf pines at age 50 were smaller diameter trees than the loblolly pines. The average codominant and dominant loblolly pine contained sufficient heartwood at age class 70 on site index 27 m and better sites and for all sites by age class 80. The average longleaf pine contains sufficient heartwood for RCW cavity activity on all sites at age class 90.

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Knowledge of the relationship of site quality, competitive index, tree age, and rate of growth to heartwood development in loblolly and longleaf pine is needed to identify and manage timber stands with high cavity tree potential for the endangered red-cockaded woodpecker (RCW). Information is available on foraging habitat and trees selected for cavity excavation by RCW clans (Lennartz and Henry 1985) but little information is available on what timber stands and trees have higher potential for developing into acceptable cavity trees at the earliest age. This paper discusses the relationship of site quality, competitive index, tree age, dbh, crown ratio, and rate of growth on heartwood formation at 6.7 m above ground in loblolly and longleaf pine sampled in the Southeast. Specific gravity of the inner 12.7 cm heartwood core and outer heartwood and sapwood are presented as indicators of the difficulty of cavity excavation and compared to specific gravity values of cavity trees.

A cross-section of at least 12.7 cm of heartwood at cavity height is needed to envelop most RCW cavities. Cavities can be excavated into sapwood or a combination of heartwood and sapwood, but it is rarely done. The RCW normally excavates cavities totally in heartwood (R. G. Hooper, pers. commun.). The woodpecker prefers redheart (*Phellinus pini*) heartwood infected trees for easier cavity excavation (Jackson 1977, Conner and Locke 1982, Hooper et al. 1991). Redheart is present infrequently in longleaf pine <95 years old or in loblolly pine <75 years old (Wahlenberg 1946, 1960). However, cavities have been found in trees 20 to 45 years younger (Shapiro 1983, Hopkins and Lynn 1971, Hovis and Labisky 1985). The decay: growth rate model proposed by Hooper (1988) conceptually explains the wide range in age of cavity trees. He suggested that woodpeckers selected trees based on ease of excavation and proposed the following hierarchy: (1) any growth rate with redheart infected heartwood, (2) fast-growth rate with large juvenile wood core and sound heartwood, (3) average or slow growth rate with sound heartwood.

Little research has been conducted on southern pine heartwood formation as influenced by environmental factors since the 1930s. The relative proportion of heartwood has been reported to vary directly with tree age and negatively with rate of growth (MacKinney and Chaiken 1935) and generally decreases in the bole with tree height. Loblolly and longleaf pines with large crowns and rapid growth on good, moist sites are reported to contain a smaller proportion of heartwood than trees with small crowns from closely stocked stands on poor drier sites (Paul 1932, Bray and Paul 1934).

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Methods

Stands representing a range of age classes (30 to 170 years) and site indices (12 m to 37 m at base age 50) were sampled for heartwood and sapwood content. Loblolly pine stands ($N = 29$) located on the Oconee National Forest (NF) in Georgia and the Francis Marion National Forest and Belle W. Baruch Forest Science Institute Hobcaw Forest in South Carolina were sampled. Sampled longleaf stands ($N = 26$) were located on the Francis Marion NF and Hobcaw Forest in South Carolina and the Talladega and Conecuh NF's in Alabama.

Twenty trees >23 cm dbh were randomly selected within each stand. Dbh, total height, and height-to-base of full live crown were recorded for each tree. A competitive index or point density measurement (m^2/ha) was determined for each tree using a 10 BAF prism (Spurr 1962). Two, 12-mm increment cores were extracted from each tree at breast height. Five of the 20 trees sampled in each stand were climbed, diameter outside bark (dob) measured, and 2 5-mm increment cores removed at 6.7 m. On 3 of the loblolly plots the trees sampled at 6.7 m were also sampled at 9.8 m for wood properties.

One core collected at 1.4, 6.7 and 9.8 m was dried, glued in a core holder, and sanded. Each core was stained using a benzidine-sodium nitrite solution to distinguish heartwood and sapwood (Kutscha and Sacks 1962). The age and length of heartwood and sapwood was recorded for each core. A second core sampled at each level was divided into 2 sections: 1) 6.4 cm next to the pith—inner heartwood and 2) remainder of the core—outer heartwood and sapwood. Wood specific gravity was determined for each section. Age at 1.4 m was converted to tree age at stump by adding 3 years for loblolly pine and 6 years for longleaf pine. Site index was determined using curves developed by the USDA Forest Service (1976).

Thirteen longleaf pine and 7 loblolly pine trees blown over on the Francis Marion NF by Hurricane Hugo with active RCW cavities were destructively sampled for wood properties. The cavity trees sampled were not a random sample of the population of cavity trees on the forest but a sample of the cavity trees destroyed by the storm. Cross-sectional disks 3.8 cm thick were removed from each tree at approximately 0.3 m above and below the cavity. Diameter of heartwood, sapwood thickness, and specific gravity of the inner heartwood core, outer heartwood, and sapwood were determined for the disks collected from cavity trees.

Correlation coefficients (r) were developed to evaluate the relationship of heartwood diameter and sapwood thickness at 6.7 m to tree age, dbh, growth rate, crown ratio, site index, and competitive index. A linear equation was developed for each species to predict diameter of heartwood and sapwood thickness at 6.7 m from variables measured at 1.4 m.

A t-test was performed to test the null hypothesis that specific gravity of the 12.7 cm heartwood core at 6.7 m for loblolly and longleaf pine was similar and specific gravity of the outer heartwood and sapwood at 6.7 m for loblolly and longleaf pine was similar. A paired t-test was performed to test the null hypothesis that diameter of heartwood at 6.7 m was similar to diameter of heartwood at 9.8 m.

Results and Discussion

Average site index for the longleaf stands was 22 m compared to 26 m for the loblolly stands. Loblolly pine trees sampled (N = 577) were growing at an average rate of 0.61 cm diameter inside bark (dib) at breast height per year compared to 0.48 cm for longleaf pine (N = 519). Average age of the longleaf sampled was 75 years compared to 64 years for loblolly pine and the longleaf pine averaged 34.5 cm dbh compared to 39.4 cm for the loblolly pine.

Heartwood diameter at 6.7 m was singificantly correlated with tree age and dbh (Table 1). Average annual diameter growth at dbh was negatively correlated with heartwood diameter at 6.7 m because the sample trees with the most heartwood were the oldest and growing the slowest. The tree characteristic that was most highly correlated with heartwood diameter at 6.7 m was diameter of heartwood at dbh.

Crown ratio had a significant but low negative correlation with heartwood diameter at 6.7 m for loblolly pine but was not significantly correlated for longleaf

Table 1. Correlation of diameter of heartwood at 6.7 m with tree and stand characteristics for loblolly and longleaf pine sampled in the Southeast United States

	Heartwood diameter at 6.7 m	
	Loblolly pine	Longleaf pine
Tree and stand characteristic	r	
Diameter of heartwood at 1.4 m	0.90[a]	0.88[a]
DBH	0.67[a]	0.82[a]
Age	0.74[a]	0.77[a]
Rate of diameter growth	−0.42[a]	−0.60[a]
Crown class	0.01	−0.09
Crown ratio	−0.19[a]	−0.13
Site index	0.07	−0.55[a]
Competitive index	−0.04	0.15

[a]Significant correlation at P 0.01 level

pine. Site index was not significantly related to heartwood diameter at 6.7 m in loblolly pine but was significantly correlated with heartwood diameter in the longleaf pines. This significant negative relationship occurred because no old longleaf stands on good sites were sampled, and the longleaf stands with the most heartwood were old stands growing on the poorest sites. Tree competitive index was not significantly correlated with heartwood formation.

Sapwood thickness at 6.7 m was significantly positively correlated with tree dbh, growth rate, crown ratio, and site index and negatively correlated with age, crown class, and competitive index. This indicates, as expected, that younger, fast-growing, codominant and dominant trees with large crowns on good sites with low stocking contain thicker sapwood than older slow-growing trees on heavily stocked poor sites.

Since only 144 of the 577 loblolly pine and 129 of the 519 longleaf pine trees were sampled at 1.4 and 6.7 m, the following regression equations were developed for predicting diameter of heartwood and sapwood thickness at 6.7 m for trees sampled only at 1.4 m:

Loblolly Pine

$$\begin{aligned} \text{HEART67} &= -3.39469 + 0.13860\,(\text{DBH}) + 0.02057\,(\text{AGE}) \\ &\quad + 0.63181\,(\text{HEART14}) \\ \text{SAP67} &= 1.69894 + 0.30171\,(\text{DBH}) - 0.02239\,(\text{AGE}) \\ &\quad - 0.24512\,(\text{HEART14}) \end{aligned}$$

Longleaf Pine

$$\begin{aligned} \text{HEART67} &= -5.46595 + 0.29272\,(\text{DBH}) + 0.02816\,(\text{AGE}) \\ &\quad + 0.37194\,(\text{HEART14}) \\ \text{SAP67} &= 1.45933 + 0.27648\,(\text{DBH}) - 0.01309\,(\text{AGE}) \\ &\quad - 0.20134\,(\text{HEART14}) \end{aligned}$$

where:

HEART67 = diameter of heartwood at 6.7 m in cm
SAP67 = thickness of sapwood at 6.7 m in cm
AGE = tree age at stump in years
HEART14 = diameter of heartwood at 1.4 m in cm

The heartwood equations accounted for 84% of the variation in diameter of heartwood at 6.7 m in both loblolly and longleaf pine ($S_{y.x}$ = 1.0, P = 0.0001). The sapwood thickness equation accounted for 73% of the variation in sapwood in loblolly pine ($S_{y.x}$ = 0.6, P = 0.001) and 65% of the variation in sapwood in longleaf pine ($S_{y.x}$ = 0.4, P = 0.0001). All trees sampled at 6.7 m were used to develop the equations, thus these equations should be tested before being applied in the field.

These equations were applied to each tree sampled at 1.4 m to predict diameter of heartwood and sapwood thickness at 6.7 m. Average predicted diameter of heartwood at 6.7 m increased with dbh and tree age (Table 2) and with increasing site index and age (Table 3). Thus, the youngest trees to contain sufficient heartwood for normal RCW cavity excavation ($\geq$12.7 cm) were the fastest growing trees on the best sites. Based on the values shown in Table 2, sufficient heartwood for RCW cavity activity does not occur in the average codominant or dominant tree until age 60 in either species and then only in the larger diameter trees. When predicted diameter of heartwood is averaged by site index and age class, loblolly pines that are $\geq$70 years old on site index 27 m or better sites will average $\geq$12.7 cm heartwood at 6.7 m (Table 3). At age class 80, the average codominant and dominant loblolly sampled on all site index sites contained sufficient heartwood for RCW cavity activity. The average codominant or dominant longleaf pines sampled contain sufficient heartwood for RCW cavity activity on all sites at age class 90 (Table 3). The heartwood diameters shown in Tables 2 and 3 are averages and do not show the proportion of trees sampled that contained more than average heartwood content.

Table 2. Average predicted diameter (cm) of heartwood at 6.7 m for codominant and dominant loblolly and longleaf pine by age and dbh class.

Dbh	Age class (yrs)						
class	40	50	60	70	80	90	100
Loblolly pine							
36	5.8	8.9	10.7	11.2	12.4	13.5	14.7
41	4.3	9.7	11.7	10.9	16.8	16.0	16.8
46	7.1	10.4	12.7	14.7	16.8	17.6	20.1
51		9.9	14.7	13.7	20.8	17.5	19.6
Longleaf pine							
36		10.7	11.2	12.2	11.9	14.5	15.2
41			13.5	13.5	15.0	15.7	15.7
46			15.2	16.3	17.3	16.3	19.8
51				16.5	20.1	21.8	22.8

Table 3. Average predicted diameter (cm) of heartwood at 6.7 m for codominant and dominant loblolly and longleaf pine by age and site index.

Site	Age class (yrs)						
index (m)	40	50	60	70	80	90	100
Loblolly pine							
21	1.8		11.2	10.9		17.3	19.3
24	5.6	8.6	11.4	9.4	16.5	15.5	21.6
27	5.3	8.1	11.9	15.0		16.0	17.0
30	4.8	10.7	12.2	14.7	19.1	20.1	20.8
33			11.7	14.2	16.8	22.1	25.4
Longleaf pine							
15			9.1	9.3	11.9	12.7	
18		9.9	11.9	13.5	12.4	15.2	15.3
21		8.9	10.7	11.9	14.2	16.3	17.1
24	4.8	7.9	11.2	13.2	12.2		
27	4.0	7.6					

At age class 50, 0%–25% of the loblolly pines growing on site index 24 m and better contained sufficient heartwood for RCW cavity activity (Table 4). However, none of the longleaf pine contained sufficient heartwood for RCW cavity activity until age class 60 because the longleaf pines sampled at age 50 were smaller diameter trees than the loblolly pines at age 50. The proportion of trees containing sufficient heartwood for RCW cavity activity increased with increasing dbh, site index, and age.

The thickness of sapwood at 6.7 m for the average codominant and dominant tree decreased with increasing tree age and increased with dbh and site index.

Table 4. Number of loblolly and longleaf pines sampled and proportion (%) that contained ≥12.7 cm of predicted heartwood at 6.7 m by age and site index classes[a].

Site	Age class (yrs)						
index (m)	40	50	60	70	80	90	100
Loblolly pine							
21	0[b](8)[c]	(0)	24(45)	21(42)	(0)	83(18)	100(21)
24	0(19)	10(29)	30(30)	5(18)	75(4)	75(24)	83(6)
27	0(5)	0(17)	50(2)	100(2)	(0)	88(18)	100(3)
30	0(17)	25(25)	28(18)	56(11)	95(19)	90(10)	100(11)
33	(0)	(0)	0(2)	69(16)	100(3)	100(12)	100(3)
Longleaf pine							
15	(0)	0(2)	14(7)	8(13)	40(15)	75(4)	(0)
18	(0)	(0)	50(4)	56(9)	36(25)	80(20)	87(23)
21	(0)	0(19)	22(23)	47(36)	50(2)	100(13)	100(4)
24	0(20)	0(3)	27(73)	69(39)	67(3)	(0)	(0)
27	0(15)	0(1)	(0)	(0)	(0)	(0)	(0)

[a] Codominant and dominant trees only.
[b] Proportion (%) of trees sampled containing ≥12.7 cm of heartwood.
[c] N trees sampled.

Loblolly and longleaf pine that contained sufficient heartwood for RCW activity averaged 9.4 cm and 7.6 cm of sapwood, respectively, the same as was found at cavity height in the cavity trees sampled.

Specific gravity of the 12.7 cm inner heartwood core of trees containing ≥12.7 cm heartwood at 6.7 m was 22% lower for loblolly pine (0.41) compared to longleaf pine (0.50). Specific gravity of the outer heartwood and sapwood was 11% lower for loblolly pine (0.46) compared to longleaf pine (0.51). The lower specific gravity of loblolly pine compared to longleaf pine is well documented (Wahlgren and Schumann 1975). The specific gravity of the 12.7 cm heartwood core or juvenile wood portion of the bole has also been reported in other studies (Clark and Schmidtling 1989) to be significantly lower in loblolly pine (0.44) than in longleaf pine (0.50). The significant differences ($P = 0.01$) reported in this study indicate that the heartwood core and outer heartwood and sapwood of the average loblolly pine is softer than that of the average longleaf pine.

The loblolly pine cavity trees sampled ($N = 7$) average 87 years old and had an average of 20.3 cm of heartwood at an average cavity height of 10.4 m. The longleaf pine cavity trees sampled ($N = 13$) averaged 20.8 cm of heartwood at an average cavity height of 9.1 m and were on average 124 years old.

The average specific gravity of the 12.7 cm heartwood core of loblolly pine cavity trees with redheart (0.35) was lower than that of the loblolly pine study trees (0.41). The average specific gravity of the heartwood core of longleaf pine cavity trees with redheart was also lower (0.45) than that of the longleaf study trees (0.50) but was higher than that of the loblolly study trees (0.41). The average specific gravity of the outer heartwood and sapwood was the same (0.46) for the loblolly pine cavity and study trees but higher in longleaf study trees (0.51) compared to longleaf cavity trees with redheart (0.46) or without redheart (0.43). These differences in wood specific gravity suggest the RCW might be able to excavate fast-growing low specific gravity loblolly pine without redheart but might prefer to wait for redheart to soften the average longleaf pine. Once a cavity is excavated in longleaf pine, however, it might be usable by the RCW for a longer period of time because longleaf is longer-lived than loblolly pine. These differences in wood specific gravity are in agreement with the decay:growth rate model for cavity tree selection proposed by Hooper (1988). Fast-growing pines have a larger juvenile wood core which contains a higher proportion of low specific-gravity earlywood cells than do slow-growing pines.

The height at which the RCW excavates cavities varies but averages about 9.1 m in the Southeast. The diameter of heartwood was significantly smaller ($P = 0.002$) at 9.8 m (10.2 cm) compared to that at 6.7 m (11.9 cm) for the loblolly pine. The diameter of heartwood decreased an average of 0.18 cm per 0.3 m increase in height above 6.7 m. Thus, to contain sufficient heartwood at 9.1 m for normal RCW cavity activity a tree must contain 14.2 cm of heartwood at 6.7 m. The average codominant and dominant loblolly pine did contain 14.2 cm or more heartwood at 6.7 m at age class 70 on site index 27 and better sites and for all sites by age class 80 (Table 3). The average longleaf pine did not contain 14.2 cm or more heartwood at 6.7 m until age class 90 and then only on site index 18 and better sites.

Conclusions

Heartwood diameter increases significantly with tree age and tree size in both loblolly and longleaf pine. Fast-growing loblolly and longleaf pines occurring on high quality sites will have the highest probability of developing sufficient heartwood (≥12.7 cm at 6.7 m) for normal RCW cavity excavation at the earliest age. At age class 50, 0%–25% of the loblolly pine growing on site index 24 m and better sites contained sufficient heartwood (≥12.7 cm at 6.7 m) for red-cockaded woodpecker cavity activity. None of the longleaf pine contained sufficient heartwood until age class 60 because the longleaf pines sampled at age 50 were smaller diameter trees than the loblolly pines at age 50.

Species differences in specific gravity of the heartwood core and outer heartwood and sapwood suggest the RCW might be able to excavate fast-growing loblolly pine with no redheart present but might prefer to wait for redheart to develop to excavate average longleaf pine.

Silvicultural practices that stimulate rapid growth of potential cavity trees throughout the rotation but maintain natural pruning are recommended to enhance heartwood formation.

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